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The literature on sea spray (superstructure) icing is almost entirely based on observations on moving ships. However, icing on stationary offshore platforms with their fixed vertical columns will differ significantly from ship icing, which is influenced by ship movement and wind and wave directions. An observation program on offshore drilling vessels is proposed, using 1-in.-diam × 8-in.-long cylinders in arrays as a standard measuring technique for spray icing. Atmospheric icing may be a source of ice accretion on derricks in some locations, and the best commercial device currently available for measuring it is

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20. Abstract (cont'd)

the Rosemount detector. Improved devices for both spray and atmospheric ice accretion measurements should be developed. Icephobic coatings have the potential for reducing ice accretion, and testing of candidate materials should be undertaken. Well-documented icing reports by all types of ships or platforms should be made and collected at a central clearinghouse.

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US Army Corps
of Engineers
Cold Regions Research &
Engineering Laboratory

Assessment of ice accretion on offshore structures

L. David Minsk

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PREFACE

This report was prepared by L. David Minsk, Research Physical Scientist, of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. This report was prepared for the Minerals Management Service (MMS) of the U.S. Department of the Interior to review the present state of knowledge of ice accretion on offshore fixed or floating platforms and to recommend approaches necessary to obtain field data on icing magnitude and frequency. Work was performed under MMS project "Offshore Structures Icing Research."

Walter Tucker and Stephen Ackley of CRREL technically reviewed the manuscript of this report.

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L. David Minsk

INTRODUCTION

Ice will accrete on a vertical surface given three conditions: (1) a source of liquid water droplets, (2) relative movement between the droplets and surface, and (3) removal of thermal energy from the liquid rapidly enough for the droplets to change phase and bond to the surface. Conditions for ice accretion on exposed horizontal surfaces are less restrictive since no horizontal movement of droplets is required, gravitational forces will be a less important factor in draining the surface, and ponding of large quantities of water can be a mechanism of ice formation.

Offshore structures have the potential for accreting massive amounts of ice whose distribution with height, coupled with the specific geometry and dynamics of the structure, will determine the threshold of instability. The ingredients for icing mentioned above will be present at Alaskan offshore sites with a high degree of probability, and therefore deserve serious consideration. These points will be considered in more detail below.

The bulk of the literature on sea spray (superstructure) icing, and it is not voluminous, reports observations of ice accumulation on moving ships, not on stationary structures. Moreover, the effects of the two components of wind direction and ship heading on ice accretion rates cannot be separated reliably, either experimentally or by analysis of these published icing reports. The shape of vessels - with a pointed prow intended to minimize resistance to forward motion and broad, nearly flat sides amidships - presents a radically different pattern to approaching waves and their accompanying winds than do the columns of stationary offshore platforms. The pattern of spray can be expected to differ significantly, though no observations to substantiate this assertion have been reported.

SPRAY DROPLET FORMATION

The bulk of droplets measured in the boundary layer near the surface of a water body result from the bursting of air bubbles at the water surface created by wind agitation. At high wind speeds direct tearing of wave crests is an additional mechanism (Wu 1982). However, this author states that "no measurements have been reported under storms," and therefore the predominant mechanism at high wind speeds is unknown.

Preobrazhenskii (1973) has reported a significant concentration of small droplets as high as 7 m (23 ft) above the ocean's surface: 7.5×10^8 droplets about 50 µm in diameter striking a 1-cm^2 area in 1 min at a wind speed U_{10} (measured 10 m above the water surface) of 15 m/s < U_{10} < 25 m/s (33.5 mi/hr < U_{10} < 56 mi/hr). The location of the oil-coated sample plates relative to the ship and the wind direction is not stated. Thus the contribution due to wave shearing and to ship geometry/sampling position cannot be stated.

ICING REPORTS

Published icing reports cannot be used as predictors of icing severity on semisubmersible vessels or drilling platforms because spray ice accretion on ships is so dependent upon ship geometry (primarily sail area, freeboard and length), ship heading relative to wind and wave directions, meteorological factors (air and water temperatures, wind speed and direction) and oceanographic factors (wave height and frequency). These reports (e.g. Wise and Comiskey 1980, Williams 1981, Aksiutin 1979, Lundqvist and Udin 1977, Mertins 1968, Shekhtman 1968, Borisenkov and Panov 1972, Borisenkov and Pchelko 1972, Panov 1976, Tabata et al. 1963) contain descriptions and estimates of ice coverage or mass distribution on a variety of vessels, but little of quantitative value applicable to other types of vessels, or even to similar vessels in different environments. These data are therefore not "transportable." Their value lies in assessing the probability of occurrence of conditions conducive to icing without specifying severity. Most observers now agree that ship icing can occur with water (surface) temperatures up to 6°C (42.8°F) and subfreezing air temperatures at wind speeds exceeding about 5 m/s (11 mi/hr). Though the paper by Williams (1981) incorporates a number of icing reports from the semisubmersible drilling vessel Ocean Bounty while at 59°N, 48'W in the lower Cook Inlet (superstructure icing occurred on 21 of the 225 days on station), no quantitative icing values are included. The best source for estimating icing from a single event is from a series of photographs made by John Reeves of the Mineral Management Service on the Ocean Bounty in December 1979; ice is visible to an estimated height of 35 ft above water level on the rig, and the thickness of some deposits appears to be 6-12 in. (Fig. 1).

METEOROLOGICAL RECORDS

Meteorological data from shore stations is of modest value in estimating conditions on the open sea. The scarcity of ship meteorological reports, and the questionable quality of many, does not permit a reliable analysis of ship icing probabilities. Despite these reservations, use has been made here of the climatic atlas of the outer continental shelf (Brower et al. 1977) to construct wind speed frequency charts for marine area C (southern Bering Sea) for the months of October, November and December. Meteorological/oceanographic data are presented in Table 1, and the monthly charts of wind speed frequency in Figure 2. The predominant direction of high wind speeds shifts from the west quadrant in October to the northeast quadrant in December (Fig. 2).

DATA REQUIREMENTS

Since the amount of ice that will accrete on a ship is a function of many variables, it is necessary to adopt a standard measurement technique to enable predictions of accumulation on vessels or structures not yet exposed to an icing environment. A simple, straightforward method for measuring spray icing would be to place short cylinders of small diameter on various parts of a vessel and to measure the accreted mass, shape and dimensions of the ice accumulation. Since collection efficiency (i.e. the ratio of the number of water droplets striking and freezing on a surface to the total number available) is higher the smaller the cylinder diameter, a cylinder of 1-in. (2.5-cm) diameter by 8-in. (20-cm) length is recommended as a standard. Arrays of these standard cylinders arranged in various orientations as shown in Figure 3 can be deployed at a number of locations on a vessel to measure the effect of exposure, height above waterline (or some representative datum) and environmental conditions. The several orientations of the cylinders are intended to determine if one is more representative than the others. Salt water brine, for example, drains from freezing sea water and typically re-

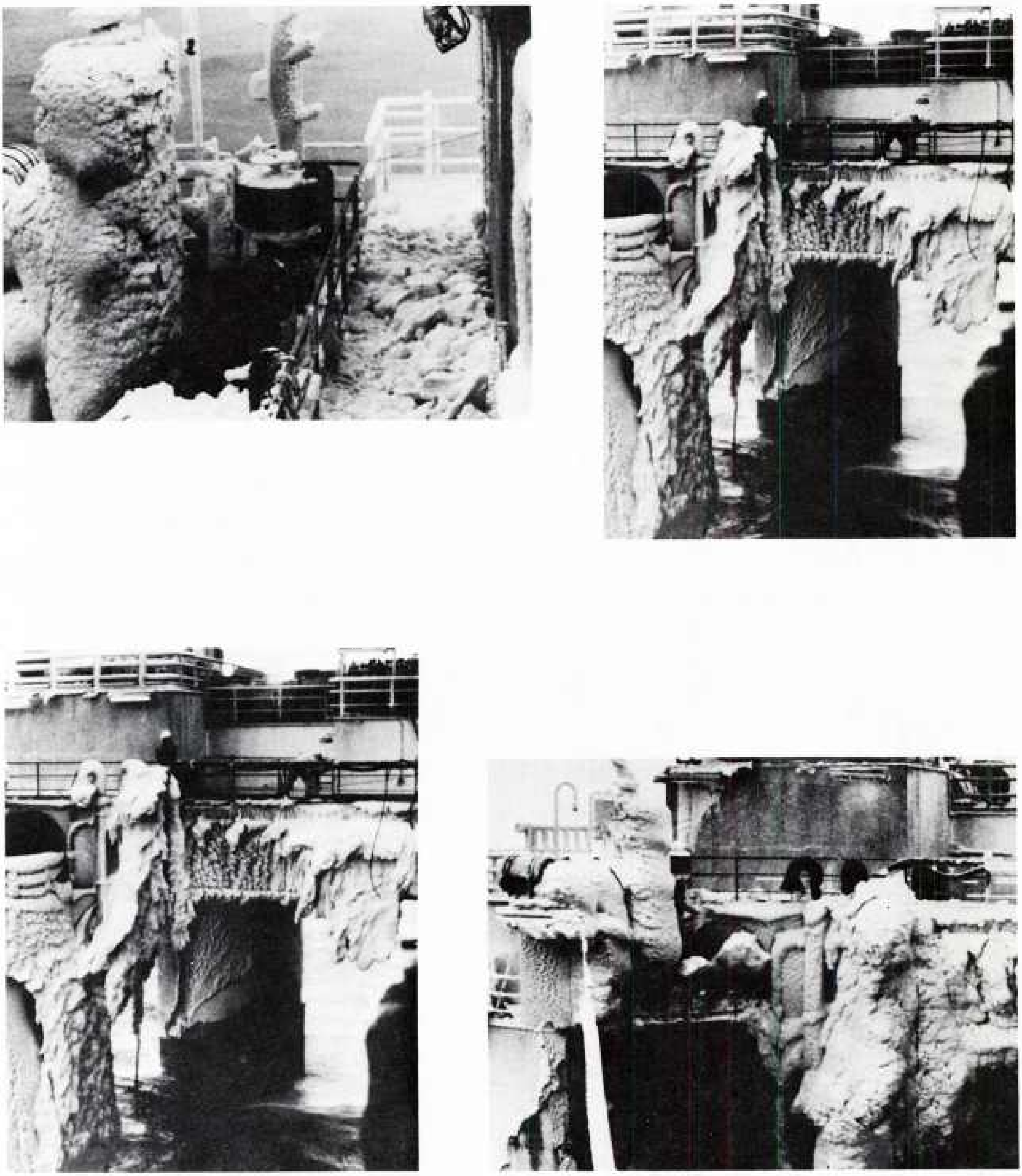

Figure 1. Ice accumulation on Ocean Bounty in lower Cook Inlet, Alaska (59°N, 152.8°W), December 1979. Estimated ice thickness is 6-12 in. and maximum height is estimated at 35 ft above water level (photos by John Reeves).

Table 1. Meteorological/oceanographic conditions in marine areas (Brower et al. 1977).

Characteristic	October	November	December
Precip. direction (liq/snow) (%)	SE(33/2)	SE(23/9)	SE(15/5)
	S(31/2)	S(24/5)	S(23/5)
	N(13/5)	N(11/24)	N(3/37)
Precip. (all) (%)			
Slight	11	11	11
Moderate-heavy	11	18	17
Mean air temp (°C)	+4 to +5	+2 to +3	-1 to 0
Wet bulb temp (°C), 80% of obs.	≤6.5	≤4.5	≤3.5
RH (50% of all obs.) (%)	≤85	≤85	≤90
Wind speed/direction			
NW (%)	21	13	10
7-10 knots (%)	2	2	1
11-16	4	3	2
17-21	5	2	2
SE	9	11	11
7-10	1	1	1
11-16	3	4	2
17-21	2	1	2
S	9	9	11
7-10	1	1	1
11-16	3	1	3
17-21	1	1	3
N	13	13	15
7-10	2	2	2
11-16	3	3	3
17-21	3	3	3
Low cloud ceiling 0-1500 ft (%) (from <1/2 to <5 n. mi. vis.) (no. obs. = 1044)	5	9	7
Wave ht./direction			
Nw (%)	20	12	10
2-m ht (%)	7	3	2
S	9	6	10
2-m ht	3	1	4
SE	9	10	11
2-m ht	5	3	4
N	11	13	14
2-m ht	5	4	4

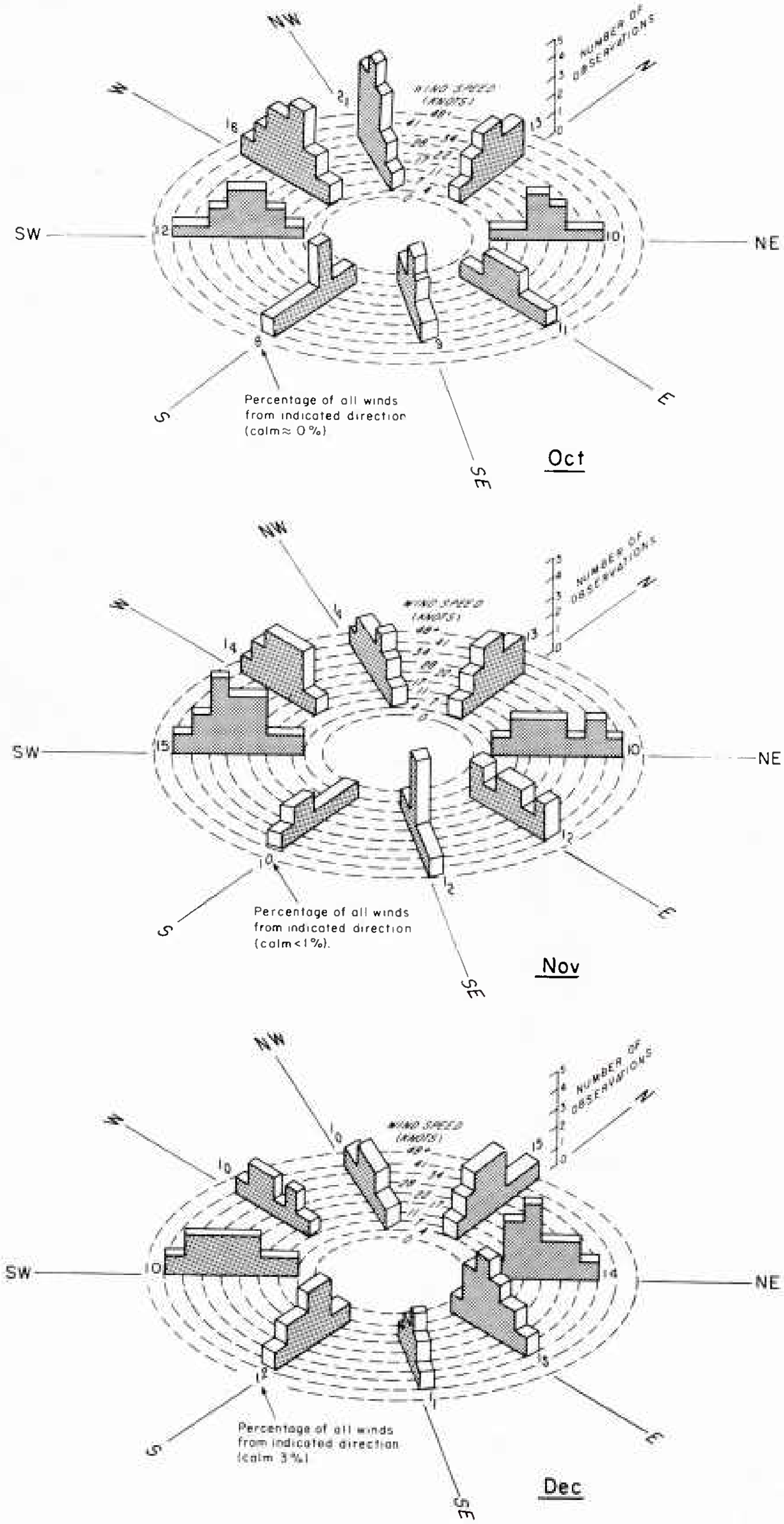

Figure 2. Wind speed/direction frequencies for October-December, Marine Area C.

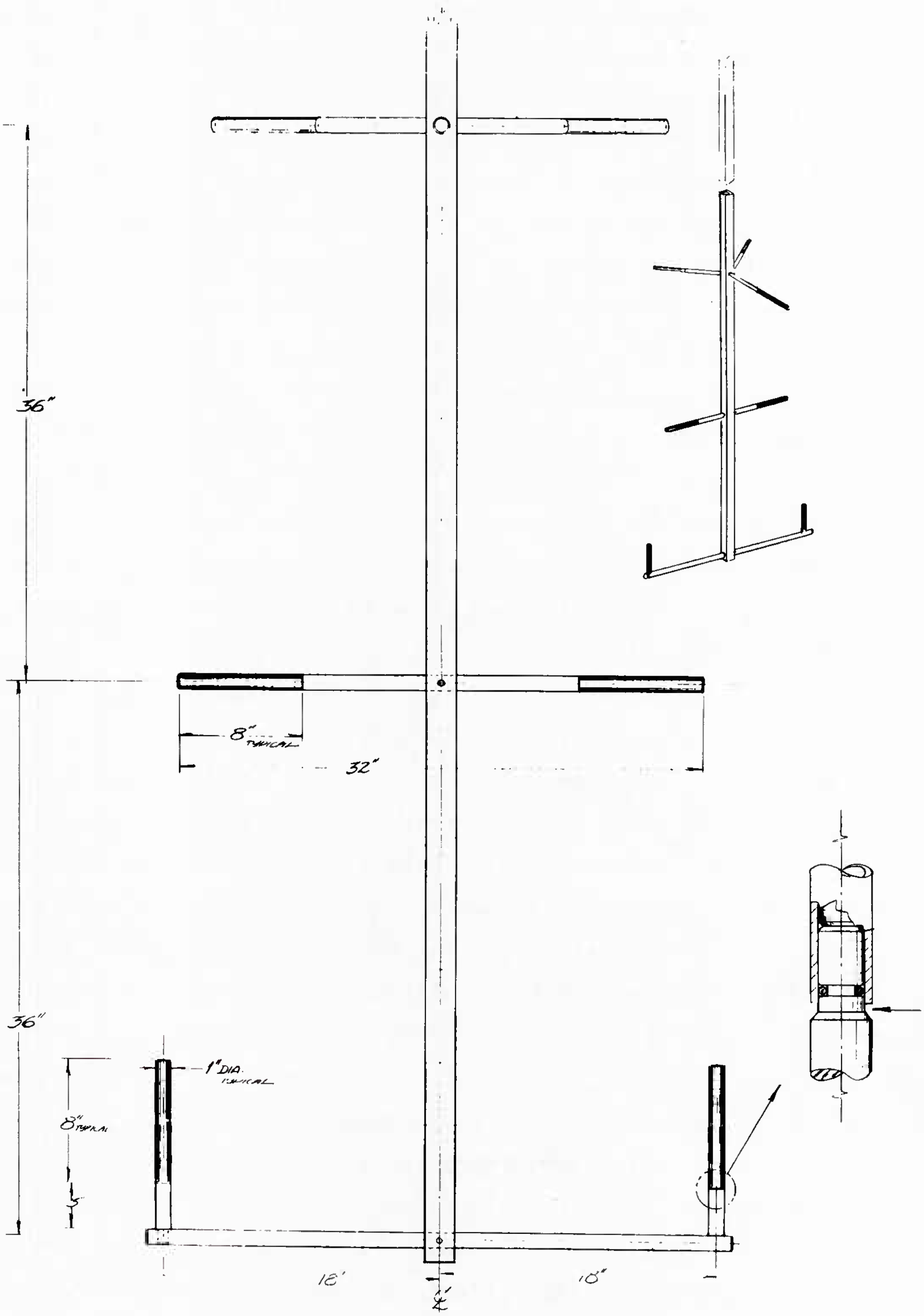

Figure 3. Experimental arrays of short cylinders for measuring spray ice accretion.

sults in a conical formation on a vertical cylinder (large diameter at bottom), according to observations by Tabata et al. (1963). However, horizontal cylinders may be preferable if the spray pattern on such vessels as semisubmersible drill rigs differs markedly from that on ships.

Careful observations and measurements should be made for the purpose of selecting a standard technique. The cylinders mounted on the array (Fig. 3) are attached to their support members with short, coarse-threaded studs or detented quick-connects, but to keep water from penetrating the joint and cementing the parts upon freezing, O-rings, Teflon washers, silicone grease, or combinations of these can be used. A hot knife or a soldering gun with cutting wire may be needed to cut the ice at the stud/cylinder junction if an ice sheath has formed. Weighing the cylinder and its accreted ice after removal from the array is the preferred method of determining accretion amount (and accumulation rate when measured over a known time interval). Profiling the ice to determine volume or radial growth is also desirable. Manual methods of profiling must be used unless an automated procedure is developed. Manual methods include use of calipers to transfer radial measurements at a number of points along the axis to paper, or the use of a commercial contour gage to transfer the shape along the axis of the cylinder at a number of radial locations (e.g. a line in each quadrant, 90° apart) to paper. Experimentation will be necessary.

Though atmospheric icing (i.e. icing due to freezing rain, fog, or wet snow) rarely causes instability of small vessels (Panov 1971), the potential for a much greater accumulation exists in the case of drilling vessels or platforms. The multiplicity of relatively small diameter structural members presents a significant sail area which, though well above the spray icing zone (about 60 ft or 90 m above the spray source), can accrete large masses of snow or ice from atmospheric sources. Measurements of icing rate can be accomplished using fixed or rotating cylinders (Brun et al. 1955) or by use of a commercially available icing detector. This detector, made by Rosemount Inc., Minneapolis, Minnesota, was originally designed for detection and measurement of ice in turbine inlets. It has since been adapted to ice measurement on aircraft and on land-based structures such as antenna towers. It functions by accreting ice on a small diameter tube which is vibrating axially at 40 kHz. The accreted mass detunes a resonant circuit and, at a preset frequency off-resonance, an alarm circuit is triggered that simultaneously energizes a heater in the support strut for 6-7 seconds to melt the ice. The normal factory-set threshold activates the trigger upon accretion of 0.02 in. of ice. Counting the number of deicing cycles over a known time provides an estimate of icing rate. Suitable corrections must be made for the dead-time caused by the heating cycle in order to improve accuracy of the estimate. Though the Rosemount detector has several drawbacks - it is a relatively delicate and expensive device that requires the availability of significant power for the heating cycle (325 W) and does not self-clean completely under low wind conditions - it is the only off-the-shelf device currently available.

ICEPHOBIC COATINGS

For a number of years CRREL has pursued a search for effective, long-lived low energy surfaces to which ice would have a low strength of adhesion. Much of the study has focused on the need for a coating that would reduce adhesion of ice on helicopter rotor blades, an application which entails a high resistance to rain droplet impaction (Minsk 1980). A number of newly developed silicone-based compounds show great promise. Another coating was developed by Jellinek under CRREL contract to be applied to navigational lock walls to reduce the massive ice buildup that adheres tightly to the walls when compressed by passage of ships (Jellinek et al. 1978). The material developed, a block copolymer, is formulated to remain effective after long immersion in (fresh) water. The reduction in strength of adhesion of ice to structural surfaces provided by icephobic coatings suggests this approach for investigation on semisubmersible drilling vessels, particularly on the understructure above the wave zone but within the spray zone. Test panels coated with various materials shown by prior CRREL work to be most promising should be deployed on test vessels. Panels must be offset from any underlying surface by at least 6 in. to avoid ice bridging (ice accumulating on the surface surrounding a small test panel may form a continuous sheet across the panel even though ice may not be adhering to it).

RECOMMENDATIONS

Icing reports

Though ship icing reports are not reliable indicators of either icing occurrence or icing severity, they do have value when collected over several years' time to delineate geographical areas where icing is possible. Assessment of icing frequency from ship reports for the purpose of constructing probability charts is not advisable because of the generally random coincidence of ship location and icing conditions; i.e. the number of reported icing events may merely be proportional to the number of ships in an area and not to the number of meteorologically likely icing conditions. Nonetheless, we recommend that a central office be established for the collection and analysis of icing reports from ships in Alaskan waters. This has been done in the past by Albert Comiskey under contract with the Alaska Environmental Information and Data Center (AEIDC) of the University of Alaska, Anchorage. For continuity, it would be desirable for a ship icing report program to be funded at AEIDC, and the skills, knowledge, and experience of the past participants utilized.

Observations

A standard method of measuring ice accretion to eliminate site-specific attributes should be developed. To investigate one approach, the cylinder arrays shown in Figure 3 should be mounted in a number of locations on a semisubmersible drilling vessel or on a fixed platform operating in potential spray icing environments. Placement at different heights above mean sea level and in different exposures will gain insight into the influence of these factors. Future work can be undertaken to develop an automatic icing rate measurement device suitable for use in spray conditions, one that would not require such a high degree of observer attention as the static cylinder arrays. Though the Rosemount detectors can continue to be used for measurement of atmospheric icing rates, consideration should be given to development of an improved device.

Until such time when improved measurement devices are available, we suggest that all operations planned for potential icing environments be encouraged to mount several cylinder arrays on rigs and to make observations. The present lack of data has led to many assumptions regarding design, operation, and safety requirements that can only be refined by more (and better) data.

LITERATURE CITED

Aksiutin, L.R. (1979) Icing of ships (in Russian). Leningrad: Sudostroenie, 126 pp.

Borisenkov, E.P. and V.V. Panov (1972) Basic results and perspectives on the investigation of hydrometeorological conditions related to ship icing (in Russian). Leningrad: Arkticheskii i antarkticheskii nauchno-issledovatel'skii institut, Trudy, vol. 298, p. 5-33. Also U.S.A. Cold Regions Research and Engineering Laboratory Draft Translation 411, AD A003215.

Borisenkov, E.P. and I.G. Pchelko (1972) Indicators for forecasting ship icing (in Russian). Leningrad: Arkticheskii i antarkticheskii nauchno issledovatel'skii institut. Also U.S.A. Cold Regions Research and Engineering Laboratory Draft Translation 481, 1975, 60 pp. AD A030113.

Brower, W.A., H.F. Diaz, A.S. Prechtel, H.W. Searby, and J.L. Wise (1977) Climatic atlas of the outer continental shelf waters and coastal regions of Alaska. Vol. II, Bering Sea. Anchorage: Arctic Environmental Information and Data Center, University of Alaska (32-3972, vol. II).

Brun, R.J., W. Lewis, P.J. Perkins and J.S. Serafini (1955) Impingement of cloud droplets on a cylinder and procedure for measuring liquid-water content and droplet sizes in supercooled clouds by rotating multicylinder method. NACA-TR-1215, National Advisory Committee for Aeronautics, Washington.

Jellinek, H.H.G., H. Kachi, S. Kittaka, M. Lee. and R. Yokota (1978) Ice releasing block-copolymer coatings. Colloid and Polymer Science, 256: 544-51.

Lundqvist, J.E. and I. Udin (1977) Ice accretion on ships with emphasis on Baltic conditions. Research Report no. 23, Winter Navigation Research Board (Swedish Administration of Shipping and Navigation, Finnish: Board of Navigation), Norrkoping (32-3308).

Mertins, H.O. (1968) Icing on fishing vessels due to spray. Marine Observer, 38(221): 128-30.

Minsk, L.D. (1980) Ice adhesion tests on coatings subjected to rain erosion. U.S.A. Cold Regions Research and Engineering Laboratory Special Report 80-28. ADA-089 698.

Panov, V.V. (1971a) Calculation of the quantity of ice accumulation on ships during spray icing. In Theoretical and experimental studies of ship icing (in Russian). Leningrad: Gidrometeoizdat, p. 26-48.

Panov, V.V. (1971b) Frequency and degree of spraying of the SRT-type ships. In Theoretical and experimental studies of ship icing (in Russian). Leningrad: Gidrometeoizdat, p. 87-90.

Panov, V.V. (1976) Icing of ships (in Russian). Leningrad: Arkticheskii i antarkticheskii nauchno-issledovatel'skii institut. Trudy 334, p. 4-25. English trans.: Polar Geography, II(3): 166-86 (July-Sep 1978).

Preobrazhenskii, L.IU. (1973) Estimate of the content of spray-drops in the near-water layer of the atmosphere. Fluid Mechanics - Soviet Research, 2(2): 95-100.

Shekhtman, A.N. (1968) The probability and intensity of the icing-up of ocean-going vessels (in Russian). Moscow: Nauchno-issledovatel'skii institut aeroklimatologii. Trudy 50, pp. 55-65.

Stallabrass, J.R. (1980) Trawler icing. A compilation of work done at NRC. Mechanical Engineering Report MD-56 (NRC No. 19372), Division of Mechanical Engineering, National Research Council of Canada, Ottawa (35-4222).

Tabata, T., S. Iwata and N. Ono (1963) Studies on the ice accumulation on ships. I (in Japanese). Low Temperature Science, A21: 173-221.

Williams, J.A. (1981) Charting heavy Alaskan weather. Offshore, 41(6): 49-54.

Wise, J.L. and A.L. Comiskey (1980) Superstructure icing in Alaskan waters. NOAA Special Report, Pacific Marine Environmental Laboratory, Seattle, WA (PB 81-135188).

Wu, J. (1982) Sea spray: A further look. Journal of Geophysical Research, 87(C41): 8905-12.

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